Field Studies at Yucca Mountain

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Field studies have played a major role in the Yucca Mountain Project Site Characterization (YMP) since the 1970s. They have ranged from the initial surface-based borehole studies that began in the 1970s to tests conducted in the Exploratory Studies Facility (ESF), an elaborate underground installation built at the site in 1997, to various present-day experiments being conducted at remote sites around the Yucca Mountain region. In this paper we will discuss surface-based borehole testing, the Cross Drift Test and other tests in the ESF, and the Busted Butte Unsaturated Zone Test.

Borehole Studies

In the 1970s, 1980s, and early 1990s, surface-based borehole testing was the major focus of field studies at Yucca Mountain. To characterize the unsaturated and saturated zones, over 300 boreholes were drilled, many of them thousands of feet deep, above and below the water table. In Figure 1, we see an example of a typical rig used for borehole drilling.

Throughout this 20-year period, borehole-based research was conducted in a number of areas: (1) lithostratigraphy of the volcanic sequence; (2) mineralogic-petrologic characteristics of the lithostra-tigraphic units; (3) hydrologic properties of the hydrostratigraphic units; (4) thermal and mechanical properties of the thermal-mechanical units; (5) near-surface hydrology, using data from shallow boreholes; (6) hydrologic monitoring of the unsaturated zone; (7) potentiometric surface determination in the Yucca Mountain region; and (8) hydraulic and transport testing in deep boreholes to investigate the saturated-zone volcanic and carbonate aquifers.

Characterization of the core from a borehole typically consists of examining and analyzing the extracted core, and the use of geophysical techniques, such as neutron and video logging, to obtain downhole information. When the drilling is completed, instrumentation in the form of packer strings or other configurations is installed downhole to make a myriad of measurements, which provide additional data.

Figure 1. Drilling into Yucca Mountain.
A typical rig used to drill one of the 317 boreholes in Yucca Mountain.

The ESF

In the late 1980s and early 1990s, the YMP continued the surface-based borehole testing program; in addition, YMP began to cite an underground test facility, the ESF, which would be used to conduct experiments to further characterize the unsaturated zone above and within the potential repository horizon.

Several design alternatives were evaluated, including many different shaft and ramp-type tunnels; the design selected was the ramp type consisting of a north ramp, main drift, and south ramp. In Figure 2, we see the ramps of the ESF, bordered by the potential repository.

The ESF construction began in 1994 and was completed in 1997; the 5-mile loop was excavated using a 25-foot-diameter tunnel-boring machine. This machine tunneled through rocks of the Tiva Canyon, Paintbrush nonwelded tuff (PTn), and upper parts of the Topopah Spring tuff formations. The upper portion of the potential repository horizon (primarily the Topopah Spring middle nonlithophysal unit) is exposed in the ESF.

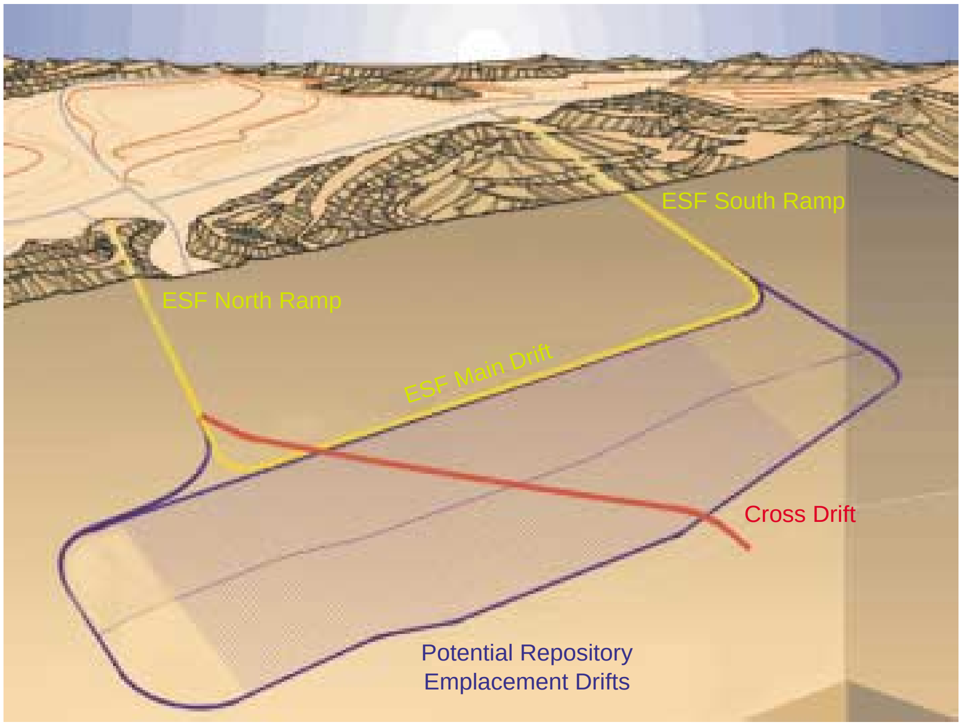

Figure 2. Potential Yucca Mountain Repository.
This cutaway shows the ramps and main drift for the Exploratory Studies Facility (yellow), completed in 1997, and the Cross Drift (red), completed in 1998, which are used to carry out a variety of tests in support of site characterization. The potential repository block is shown in blue.

Numerous research activities have been conducted in the ESF. They include geologic mapping, construction monitoring, and systematic sampling and characterization of the hydrologic, mineralogic-petrologic, thermal-mechanical, and geochemical properties of the stratigraphic units in the unsaturated zone.

A series of alcoves and niches were excavated in the ESF (Figure 3) so more specific experiments to characterize hydrologic and thermally coupled processes further could be conducted. These tests included characterizing hydrologic properties of the Tiva Canyon and PTn (Alcoves 1, 3, and 4) and of the faults in the Yucca Mountain region, namely the Bow Ridge Fault and Ghost Dance Fault (Alcove 2 and Alcoves 6 and 7, respectively). The tests also investigated thermally coupled processes in potential repository horizon rocks (Topopah Spring middle nonlithophysal unit) in Alcove 5 (Single Heater and Drift Scale Test).

Drift Scale Test. The largest and most visible test executed by the YMP in the ESF to date is the Drift Scale Test, located in Alcove 5. This test is centered around a 47-m-long simulated emplacement drift loaded with nine simulated waste packages. The drift and surrounding rock mass is instrumented with thousands of sensors, and the rock mass is heated to 200°C.

The purpose of this test is to evaluate the thermal-hydrologic-mechanical-chemical coupled processes in the potential repository horizon rocks at field scale. Results for the three (of four) years of planned heating suggest that heat transfer is conduction-dominated, with a key role played by convection of moisture. The results also indicate that pore water mobilized by heat tends to move below the heated region rather than stay "ponded" above the drift. As expected, coupled process phenomena also occur at sub-boiling temperatures.

Other Studies in the ESF. In the mid-1990s, the Project dedicated considerable effort to understanding (1) surface infiltration, (2) the role of the PTn (nonwelded vitric tuff) in attenuating and dampening of infiltration fluxes, and (3) the resultant percolation fluxes in the potential repository horizon. Researchers used geochemical and mineralogic-petrologic evidence to better understand these important phenomena, especially percolation flux in the potential repository horizon.

Two notable data sets resulted from these studies: (1) findings on the distribution of ^{36}Cl and Cl and (2) geochronologic and geochemical results on fracture-filling minerals (primarily calcite and opal) and systematic rock samples (Sr isotope data in particular) throughout the ESF.

This work provided very useful data for the calibration of the unsaturated-zone site-scale flow and transport model. More important, the investigations of percolation flux led to the construction of four testing niches in the ESF within the Topopah Spring middle nonlithophysal unit (Niches 1, 2, 3, and 4). Testing in these niches has focused on the relationship between percolation flux and seepage into drifts (i.e., how much of the percolation flux actually enters, or "seeps," into an opening). This issue is now a key factor in understanding the performance of the natural system at Yucca Mountain because of its implication as to how much moisture may be expected to contact the waste packages eventually.

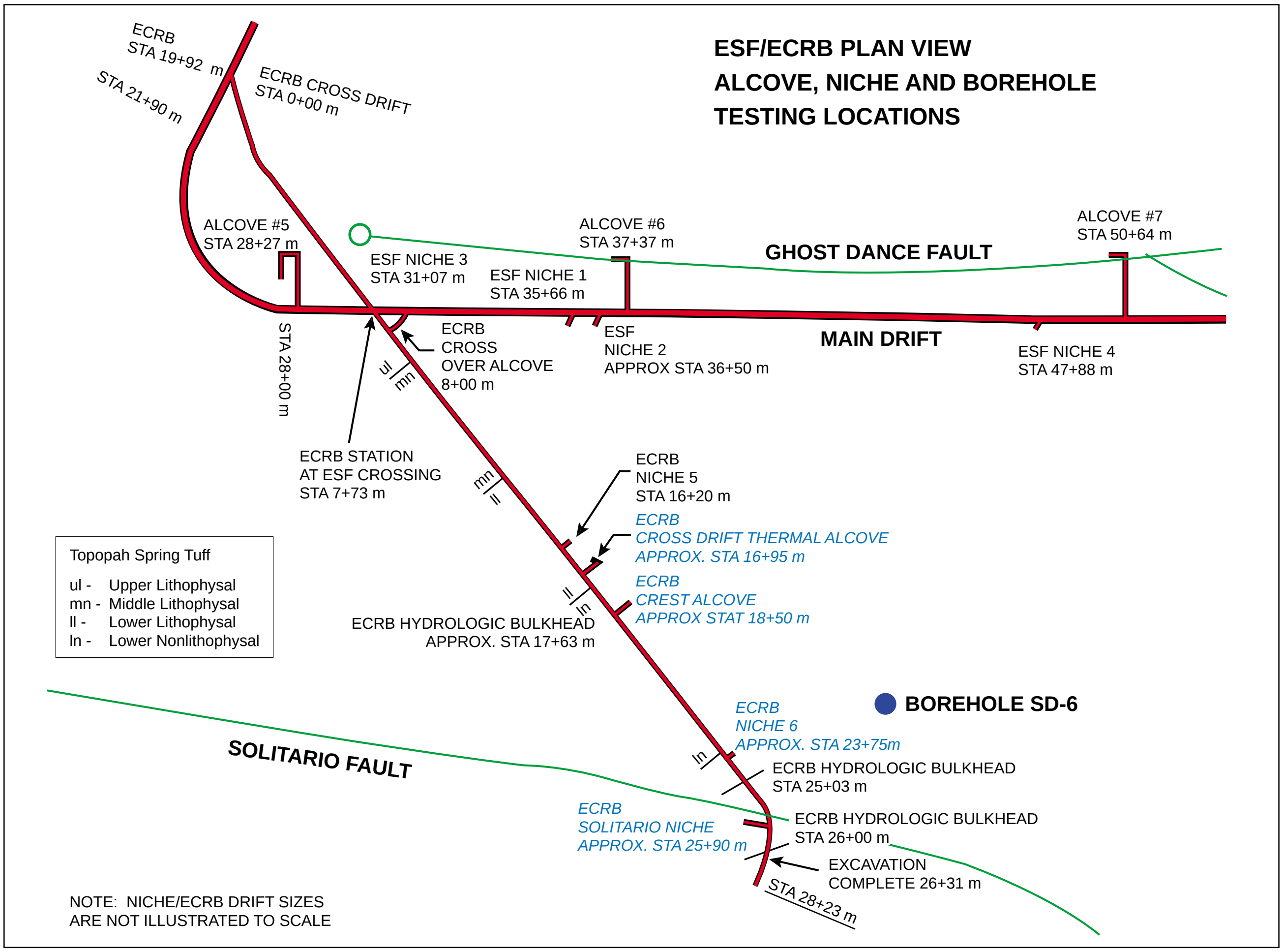

Figure 3. Plan View of the Exploratory Studies Facility and the Enhanced Characterization of the Repository Block (ECRB). The plan shows the locations of the various boreholes, alcoves, and niches used for testing, as well as the locations of the Ghost Dance and Solitario faults. The extent of the layers of the Topopah Spring Tuff are indicated with abbreviations along the Cross Drift.

In summary, the ESF niche studies suggest that the percolation flux needed to initiate seepage may be much higher than is currently observed or would even occur under wetter climate conditions in the future.

The Cross Drift Studies

One of the limitations of the ESF is that it does not expose the majority of the potential repository horizon rocks (most of the Topopah Spring lower lithophysal unit and all of the Topopah Spring lower nonlithophysal unit). Based on these limitations and numerous interactions with external oversight bodies (particularly the Nuclear Waste Technical Review Board), the YMP initiated a planning effort, termed the Enhanced Characterization of the Repository Block (ECRB), in 1997.

This effort was aimed to plan a way to characterize the potential repository block further. The result of this effort was the construction of an additional tunnel (termed the Cross Drift) across the potential repository block to expose the potential repository horizon units and the Solitario Canyon fault zone. The Cross Drift is shown in Figures 2 and 3.

Construction of the Cross Drift started in late 1997 and was completed in October 1998. Initial activities in the Cross Drift included geologic mapping, systematic sampling and analyzing hydrologic and geochemical properties, and hydrologic monitoring (all within the Topopah Spring tuff formation and the Solitario Canyon fault zone).

As in the ESF, a series of testing alcoves and niches are being developed for the Cross Drift over the next couple of years. These studies will address flow, transport, and seepage properties (Hydrologic Bulkhead Studies, Crossover Alcove, Niches 5 and 6, and Crest Alcove). Thermally coupled processes (Cross Drift Thermal Test) within the potential repository horizon rocks and the hydrologic properties of the Solitario Canyon fault zone (Hydrologic Bulkhead Studies and Solitario Canyon Fault Alcove Testing) will also be studied.

Busted Butte Unsaturated Zone Transport Test

In addition to surface and underground tests, there are experiments being conducted at remote sites around Yucca Mountain. The most notable test is the Busted Butte Unsaturated Zone Transport Test.

The goals of this testing program are to evaluate the influence of heterogeneities on flow and transport, including other aspects of the system such as fracture/matrix interactions and permeability contrast boundaries. It also considers colloid migration in the unsaturated zone. The tests are conducted in a 25-m-long underground alcove excavated at Busted Butte (Figure 4). The alcove is at the end of a long access tunnel from the surface.

Our observations so far suggest that porous media flow dominates in the vitric Calico Hills. Data both from boreholes surrounding the repository and from Busted Butte will build confidence in the unsaturated-zone flow and transport models used by the YMP. These data may show that measured sorption values for Busted Butte (vitric) rocks are greater than those currently used in models.

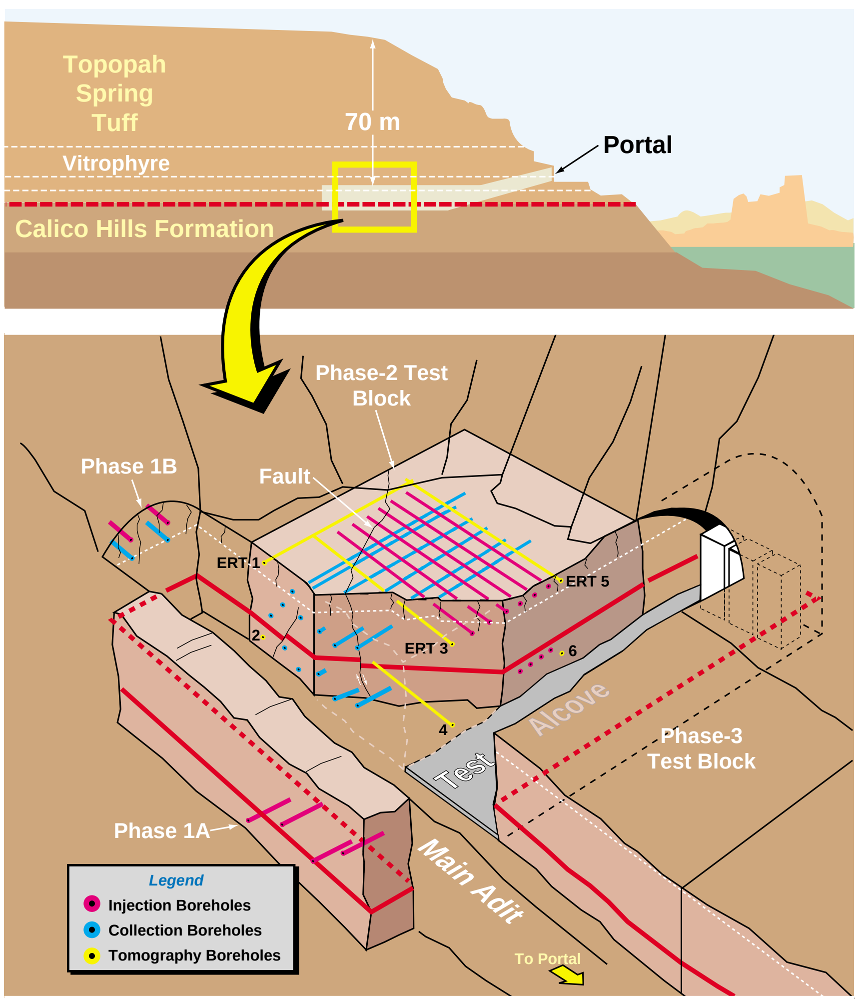

Figure 4. Busted Butte Unsaturated Zone Transport Test.
The diagram shows the layout of the field test taking place in Busted Butte that uses tracer solutions to study transport through the unsaturated zone.

Conclusions

Results from field tests at Yucca Mountain continue to provide a significant portion of the technical basis for process models, performance assessments, and repository design to support key programmatic milestones such as the 1998 Yucca Mountain Viability Assessment and the upcoming Yucca Mountain Site Recommendation. ■

Further Reading

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor). 2000. *Yucca Mountain Site Description*. TDR-CRW-GS-00001, REV 01, ICN 01. Las Vegas, NV: U.S. Department of Energy, Yucca Mountain Site Characterization Office.

Bussod, G. Y., H. J. Turin, and W. E. Lowry. 1999. Busted Butte unsaturated zone transport test: Fiscal Year 1998 status report. Los Alamos National Laboratory report LA-13670-SR.